ANALYSIS OF VOICE OVER IP DURING VERTICAL HANDOVERS IN HETEROGENEOUS WIRELESS AND MOBILE NETWORKS

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ABSTRACT

Roaming across different heterogeneous technologies such as 802.11, WiMAX and UMTS will become a requirement of future networking devices, especially for Voice over IP traffic, which nowadays is one of the most important services regarding the performance evaluation of wireline and wireless networks.

In this paper we perform a study on the performance of voice packet transmissions during vertical handovers between 3G-HSPA, WiMAX (IEEE 802.16) and WLAN (IEEE 802.11) wireless networks. In particular, we analyze the performance metrics, such as handover latency and packet loss, for obtaining the effects of vertical handover on the mobile node performance, by using the recommended parameter values for link triggers and router configuration in IEEE 802.21 standard.

Results show that the handover latency is severely impacted by the choice of the time interval parameters on the link layer, especially in the case of UMTS to WiMAX vertical handover. Packet loss is also analyzed in order to have the best optimization in vertical handovers between UMTS, WiMAX and WLAN, for Voice over IP traffic.

I. INTRODUCTION

Next-generation wireless networks have been envisioned as an IP-based infrastructure with the integration of various wireless access networks such as IEEE 802.11 wireless local area networks (WLANs), IEEE 802.16 wireless metropolitan area networks (WMANs), and Universal Mobile Telecommunications System (UMTS). Heterogeneous wireless networks need to cooperate to provide users with seamless mobility and required quality of service (QoS). Mobile nodes can automatically switch the connectivity between different types of networks.

The vertical handover occurs when the connection to a mobile user changes from one network to the other during a call. The process of deciding and executing a vertical handover is more complex than a horizontal handover with a network such as the case that a mobile user switches its home base station. IEEE 802.21 [1] defines a media-independent handover (MIH) framework that can significantly improve handover between heterogeneous network technologies. The standard defines the tools required to exchange information, events, and commands to facilitate handover initiation and handover preparation. IEEE 802.21 does not attempt to standardize the actual handover execution mechanism. Therefore, the MIH framework is equally applicable to systems that employ mobile IP at the IP layer as to systems that employ Session Initiation Protocol (SIP) at the application layer.

On the other hand, in the recent past, there has been a tremendous increase in the popularity of VoIP services as a result of huge growth in broadband access. The same VoIP service poses new challenges when deployed over a heterogeneous wireless network while enabling users to make voice calls during vertical handovers using mobile nodes with different interfaces.

In this paper, through an extensive simulation study, the effect of DCD/UCD interval (WiMAX MAC layer parameter) on vertical handover performance for VoIP traffic according IEEE 802.21 standard has been investigated. In the simulation environment, terminals move according to the different random trajectories. Performance of vertical handovers is measured based on vertical handover latency and packet loss. According to the 802.21 standard, the handover algorithm configures the power thresholds, and then handovers are triggered by signals received from lower layers. We analyze the effect of the DCD/UCD interval on vertical handover latency and packet loss between UMTS/WiMAX/WLAN networks. The results indicate that the choice of DCD/UCD interval has great impact on the VoIP QoS during vertical handover between UMTS and WiMAX with the IEEE 802.21 specification.

This paper is organized as follows: Section II is the introduction to the VoIP and G.723.1 codec used in the simulations. Section III shows the simulation scenario. Simulation model, simulation parameters and handover performance metrics are explained in details. Section IV gives the results and analysis from the simulations and finally Section V concludes this paper.

II. VOIP TRAFFIC

In the context of IP networks, telephony services are known as Voice over IP (VoIP). A VoIP flow depending on the encoding employed, such as G.711, G.723.1 or G.729, can generate data rates between 5.33 and 64 Kbps. Packets are generated isochronously at the supported packetization rate through the real time protocol (RTP) containing a fixed size payload.

To maintain a conversation at good quality levels, a VoIP flow requires low packet loss rates. Loss rates up to 10% may be tolerated depending on the type of packet concealment technique employed by the decoder on the side of the receiver. To sustain intelligibility of VoIP communications the total end-to-end delay should remain below 150 ms or lower, for highly interactive conversations. Delays in the range of 150-400 ms are considered acceptable, although the annoyance becomes perceptible; delays greater than 400 ms are considered intolerable and thus unacceptable for effective communication.

Voice traffic has a very stringent delay constraint. It has active talking periods where the source is sending out periodic voice packets or the talker is speaking and silence periods where no voice packets are generated or the speaker is silent. Most standard voice encoding has a fixed bit rate and a fixed packetization delay. There are thus producing a stream of fixed size packets. This packet stream is however only produced during talk-spurts and the voice coder sends no packets during silence periods. The behavior of a single source is easily modeled by a simple ON-OFF model shown in Figure 1. During talk-spurts (ON periods), the model produces a stream of fixed size packets with fixed inter arrival times (T).

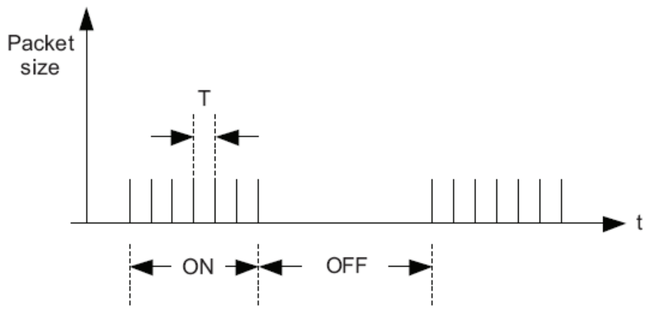

Figure 1: Characteristics of a VoIP single source.

G.723.1 codec belongs to the Algebraic Code Excited Linear Prediction (ACELP) family of codec and has two bit rates associated with it: 5.3 kbps and 6.3 kbps. The encoder functionality includes Voice Activity Detection and Comfort Noise Generation (VAD/CNG) and decoder is capable of accepting silence frames. The coder operates on speech frames of 30 ms corresponding to 240 samples at a sampling rate of 8000 samples/s and the total algorithmic delay is 37.5 ms. The codec offers good speech quality in network impairments such as frame loss and bit errors and is suitable for applications such as VoIP.

III. SIMULATION SCENARIO

A. *Simulation model*

In this section, we describe the simulation scenario of our researching. The scenario considered for the simulation results consists of one WLAN cell located inside WiMAX cell, both of them located inside an UMTS cell. All three networks are configured on 2000x2000 meters topography. IEEE 802.11 (WLAN) access point is located on x=800 meters, y=1000 meters, IEEE 802.16 (WiMAX) base station is located on x=1100 meters, y=1000 meters. UMTS base station covers the whole simulated area. 15 simulations were done with random mobile terminal node trajectories across the three networks with a speed of 10 km/h. Simulations were performed on Linux operating system using ns-2 simulator with the mobility package tool from NIST [2].

For VoIP traffic, a two-state voice traffic model was considered; During the ON-state (talk-spurt) it generates packets with fixed inter-arrival time while no packets are generated during the silence period (OFF-state). Both states are distributed exponentially with mean for the ON-period _on = 1000 ms and OFF-period _off = 1350 ms in accordance with the well-established speech conversation model proposed by Brady [3]. During the ON-period the voice IP flow carried a payload of 24 bytes transmitted at 30 ms intervals. Such data rate specification is compliant with G.723.1 codec at 6.3 Kbps.

B. *Simulation parameters*

Simulation parameters used in the simulations for this paper are recommended parameter values for link triggers and router configuration based on the previous work in this field [4-8]. Table 1 summarizes the optimized parameter values which gives the best results in handover performance metrics.

Table 1: Recommended Parameter values

Parameter	Function	Value
MIN_RA_DELAY	Router configuration	200s
Router lifetime	Router configuration	1800s
MIN_DELAY_BETWEEN_RA	Router configuration	0.03s
MAX_RA_DELAY	Router configuration	0
Missed beacon threshold	Link Down generation	2
Packet error threshold	Link Down generation	4

The other parameters from the three networks are as specified in the package tool for ns-2 simulator from NIST.

C. *Handover performance metrics*

Performance metrics used to measure effects of vertical handover on the MN (mobile node) performance in this scenario are vertical handover latency and packet loss.

The handover latency is the time needed to complete a handover. It includes the movement detection, the decision process, the new address creation/validation if needed and the redirection latency that includes a round trip time with the correspondent. The starting point of the handover is the moment when the MN enters / leaves the cell. During a handover, a MN is not able to use the interface on which it is redirecting its flow, until the handover is completed. However, during a handover, a MN might be able to send and receive data packets through another interface, which is still available for data communication.

The packet loss is the ratio between the packets discarded because of errors at the receiver and the total number of packets expected during a handover.

IV. SIMULATION RESULTS

Simulations are done using 15 random mobile node trajectories across UMTS, WiMAX and WLAN cells. On application level traffic generators in ns-2 generates VoIP traffic using G.723.1 for all 15 random mobile node trajectories. In this scenario mobile node performs four vertical handovers. The first handover from the UMTS cell to the WiMAX cell is performed when the MN (mobile node) enters the coverage area of the WiMAX base station. The second handover between the WiMAX cell and the WLAN cell is performed when the MN leaves the coverage area of the WiMAX base station and enters the WLAN hotspot located inside WiMAX coverage area. The third vertical handover occurs when MN leaves the coverage area of the WLAN AP (access point) and returns to WiMAX base station. The last vertical handover happens when MN leaves the WiMAX coverage area and returns to UMTS interface. When the MN leaves the WLAN hotspot and WiMAX cell, the MN is not able to use the WLAN and WiMAX interface during the time required to redirect the data flow on the UMTS interface.

A. Effects of DCD/UCD interval on the UMTS/WiMAX/WLAN vertical handover latency

During the vertical handover between UMTS and WiMAX when an MN scans for a new 802.16 BS, it needs to receive the DL-MAP, DCD (downlink channel descriptor), UCD (uplink channel descriptor) and UL-MAP MAC management messages. The downlink channel descriptor (DCD) and the uplink channel descriptor (UCD) define the characteristics of the physical channels. The DCD and UCD comprise the detail information of the DL burst profile and the UL burst profile. The DCD and UCD MAC messages are transmitted by the BS periodically. The maximum interval is 10 s in the standard [9]. In our simulation, with the 802.16 model from NIST, the DCD and UCD interval is set to 5 s. Furthermore, this interval is changed in the code to 1 s and the same simulations are repeated in order to analyze the effect of the DCD/UCD interval on the vertical handover latency for VoIP G.723.1 traffic.

Figure 2 presents the results of vertical handover latency in ms when MN enters the coverage area of WiMAX base stations from UMTS for VoIP traffic. This figure shows the impact of the DCD/UCD interval on the handover latency between UMTS and WiMAX. It clearly shows that the handover latency is severely impacted by the choice of the DCD/UCD interval. Using DCD/UCD interval of 5 seconds, handover latency varies from 432,425 ms to 4,52 seconds for different random simulations, and using DCD/UCD interval of 1 second it varies from 156,425 ms to 1,056 seconds. Average vertical handover latency of the 15 simulations with DCD/UCD interval of 5 seconds is 2,87 seconds and for 1 second is 641,49 ms.

Results show that decreasing of the DCD/UCD interval in the MAC management of WiMAX standard improves the vertical handover latency of the UMTS/WiMAX handover. This is especially important for VoIP traffic because it is delay sensitive. Delays greater than 400 ms are considered intolerable and thus unacceptable for effective communication. Thus we have degradation of the QoS of the mobile node using VoIP traffic during the simulated vertical handover between UMTS and WiMAX even with DCD/UCD interval of 1 second. Possible solution for this problem could be initiation of the vertical handover process between UMTS with WiMAX to be during the silence period (OFF-state).

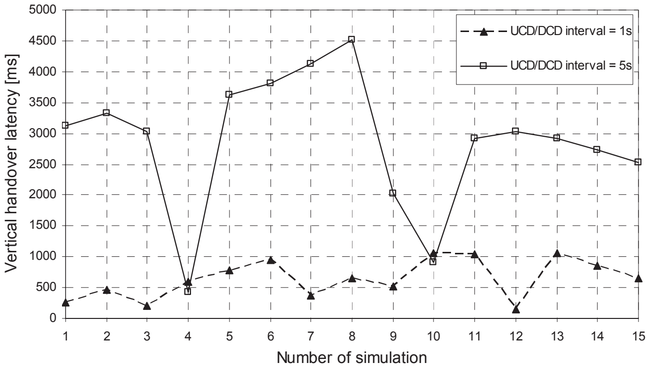

Figure 2: Effect of varying DCD and UCD interval on vertical handover latency between UMTS and WiMAX networks for VoIP (G.723.1) traffic for 15 simulations of random mobile terminal trajectories.

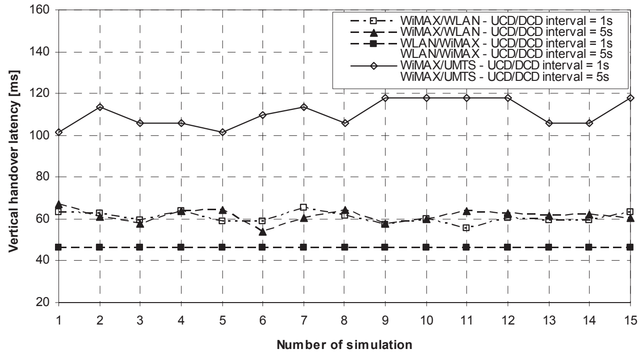

Figure 3: Vertical handover latency between WiMAX/WLAN, WLAN/WiMAX and WiMAX/UMTS networks for VoIP (G.723.1) traffic for 15 simulations of random mobile terminal trajectories.

In our case because the silent period is 1350 ms, vertical handover initiation during this period will not degrade the QoS of the user with VoIP traffic, because the worst vertical handover latency in our simulations (when DCD/UCD interval is 1 s) is 1,056 second, which is less than the OFF-state.

Reducing the synchronization time by increasing the frequency of the channel descriptor messages comes generally at the cost of a higher bandwidth overhead (less bandwidth available for user traffic). This effect reduces the capacity of the WiMAX network, so the total user traffic will be decreased at the cost of better vertical handover latency results.

Figure 3 shows the vertical handover latency results for the other three vertical handovers as mobile node trajectories crosses the WiMAX, WLAN and UMTS coverage areas. Vertical handover latency here satisfies the QoS of the VoIP user, because the vertical handover latency of all 15 random simulations is below 120 ms.

As we can see from the results, decreasing the DCD/UCD interval from 5 s to 1 s has no impact on the vertical handover latency. This case is opposite to the results in Figure 2 where

vertical handover latency is severely impacted when decreasing the DCD/UCD interval.
Reason for this kind of results is very logical. When mobile node enters the WiMAX coverage area from the UMTS network, 802.16 interface is turned off. If 802.16 is OFF, synchronization with BS (2.5s with DCD/UCD interval of 5s) is needed. Because we decreased the DCD/UCD interval to 1 second, we decreased the synchronization time during the vertical handover process. That’s why the vertical handover latency has decreased significantly.
Furthermore when MN leaves the WiMAX coverage area and enters the WLAN hotspot there is no need for synchronization in the vertical handover process. After that, when MN leaves the WLAN hotspot and returns again to WiMAX base station, 802.16 interface is still turned on. This is because when the MN enters the WLAN hotspot, it still has a connection trough the WiMAX interface, because WLAN hotspot is inside the WiMAX coverage area. Therefore, while the association is being established with the WLAN AP, the MN can still use the WiMAX interface for its data. On the other hand, when the MN leaves the WLAN cell, the MN is not be able to use the WLAN interface during the time required to redirect the data flow on the WiMAX interface. And at the last vertical handover between WiMAX and UMTS, MN leaves the WiMAX coverage area and returns to UMTS network. It doesn’t need synchronization here with DCD and UCD messages. That’s why DCD/UCD interval in Figure 3 doesn’t impact the vertical handover latency between WiMAX/WLAN, WLAN/WiMAX and WiMAX/UMTS networks.

B. *Effects of DCD/UCD interval on the packet loss during UMTS/WiMAX/WLAN vertical handovers*

Packet loss is analyzed for the same simulations presented above for the results of vertical handover latency. Table 2 and Table 3 presents the results of packet loss during the vertical handover process between UMTS and WiMAX networks, as the most critical vertical handover considering the results of vertical handover latency.
Table 2 gives the results of packet loss when using DCD/UCD interval of 5 seconds. The average number of packet loss of the VoIP traffic of the MN with the UMTS base station during the vertical handover process for all 15 simulations is 2 and with the WiMAX base station average number of packet loss is 5,13.

Table 3 shows the results for packet loss during vertical handover process when DCD/UCD interval is 1 second. Here the number of average packet loss of the VoIP user with the UMTS base station for the 15 simulations is 2. And for the connection with the WiMAX base station during the vertical handover, the number of average packet loss is 1,33.
It is obvious from the results that when using lower DCD/UCD interval the packet loss of the WiMAX connection during vertical handover process is significantly decreased. Packet loss of the UMTS connection during the vertical handover normally has the same value of 2, because DCD/UCD interval is WiMAX parameter.

Results from other papers [5] show the impact of the packet error threshold on the vertical handover latency. For the first 4 packet retransmissions corresponding to the first 4 packets lost at the MN receiver, the size of the backoff window remains small (less than 120 slots), therefore the handover latency remains relatively unaffected. As the backoff window increases for retransmissions greater than 4, the handover latency is increased. That's why the recommended value for packet error threshold in Table 1 is 4. As we can see from our results, the average number of packet loss when DCD/UCD interval is 5 seconds is 5,13. Because of this we have very high vertical handover latency in this case.

Table 2: Packet loss during vertical handover between UMTS and WiMAX with DCD/UCD = 5 s

N^0 of sim.	UMTS/WiMAX vertical handover [ms]	UMTS packet loss (%)	WiMAX packet loss (%)
1	3124,425	2	4
2	3324,425	2	10
3	3024,425	2	7
4	432,425	2	2
5	3632,425	2	10
6	3804,425	2	9
7	4132,425	2	5
8	4516,425	2	9
9	2024,425	2	1
10	916,425	2	0
11	2912,425	2	4
12	3024,425	2	4
13	2924,425	2	4
14	2724,425	2	4
15	2524,425	2	4

Table 3: Packet loss during vertical handover between UMTS and WiMAX with DCD/UCD = 1 s

N^0 of sim.	UMTS/WiMAX vertical handover [ms]	UMTS packet loss	WiMAX packet loss
1	256,425	2	0
2	464,425	2	2
3	208,425	2	1
4	600,425	2	2
5	788,425	2	3
6	948,425	2	3
7	364,425	2	1
8	656,425	2	0
9	512,425	2	0
10	1052,425	2	0
11	1044,425	2	2
12	156,425	2	0
13	1056,425	2	2
14	856,425	2	2
15	656,425	2	2

Using DCD/UCD interval of 1 second or sleep mode of the IEEE 802.16 interface will give satisfying results of packet loss during vertical handover process between UMTS and WiMAX in our simulations.

V. CONCLUSION

In this paper we have presented results of analysis for VoIP traffic (G.723.1 codec) during vertical handover between mobile and wireless networks. In particular, we have analyzed effects of the 802.16 synchronization component (DCD/UCD interval) on handover performance metrics, such as vertical handover latency and packet losses.

In fact, the delay contributed by the synchronization component is the most significant during the vertical handover process. IEEEE 802.16 synchronization phase plays a key role in the handover latency. Any prior knowledge for synchronization (channel descriptor messages) is critical in speeding up the handover.

Reducing synchronization time by increasing the frequency of the channel descriptor messages comes generally at the cost of a higher bandwidth overhead (less bandwidth available for user traffic). This is not the problem if the WiMAX cell is not fully loaded. But if we have fully loaded network better solution is to keep the 802.16 interface turned on, but then we have additional power consumption and reduced battery life.

In our results we have showed that decreasing the DCD/UCD interval from 5 seconds to 1 second gives great improvement of the vertical handover latency and packet loss. But still this improvement in vertical handover latency is not enough for strong demands for packet delay results of VoIP traffic. Proposed solution for this problem could be using algorithm which initiates vertical handover process between UMTS and WiMAX during the silence period of VoIP traffic. This solution will not degrade the QoS of the users with VoIP traffic during vertical handovers between UMTS and WiMAX. However, it is a part of the future work in this area.

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